IMPACT FLASH SPECTROSCOPY AS A MEANS TO CHARACTERIZE ASTEROID SURFACE COMPOSITIONS.

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Abstract: Hypervelocity impacts generate significant self-luminous vapor containing a wealth of spectral information. Impact Flash Spectroscopy (IFS) may allow exploiting this phenomenon to determine the composition of planetary surfaces remotely in future low-cost missions. As a test of this concept, hypervelocity impacts into three compositionally distinct meteorite types were performed using the NASA Ames Vertical Gun Range. Ratios of key emission lines (Ca, Mg, K, Na, and Fe) allowed distinguishing between three distinct meteorite classes. Consequently, this technique holds promise for uniquely characterizing the compositions of asteroids/comets.

Introduction: Impact flash was recognized as a potential tool for planetary exploration more than thirty years ago (1). More recently, emission spectra of the flash were used to probe the impact process (2, 3). Through a joint research effort to explore both the impact process and the feasibility of IFS for future mission scenarios, we have been investigating the effects of impact velocity, angle, and target/projectile combinations on the spectral content and intensity of impact-generated vapor plumes (4). Here we report a simple proof-of-concept: distinguishing among compositionally distinct meteorite classes as an analog for distinguishing among the range of possible asteroid compositions. Three meteorites were used as targets: an olivine bronzite ordinary chondrite, H4 (Salaices); a primitive CV-3 chondrite (Allende); and a differentiated achondrite (Millibillie eucrite). Each were impacted by a 0.635 cm aluminum sphere at 5.5 km/s with an impact angle of 30˚ (from the horizontal) using the NASA Ames Vertical Gun Range. X-Ray Flourescence (XRF) analyses made at Brown University provided compositional ground truth for the CV-3 and H-4 chondrites. There was not enough material of the eucrite for this analysis; consequently, its composition was assumed from published values of the bulk composition for a typical sample. Impact angle was chosen on the basis of previous experimental studies. The aluminum sphere was selected because of its reliability in launching.

Results: Figure 1 illustrates the resulting flash spectra for the three samples. The impactor signature dominates the spectra between 450 and 600 nm (AlO), with Al and Mn emissions also clearly recognized. Significant spectral information is masked by the strong AlO molecular bands, which also complicates interpretations of the aluminum content of the meteorites. Nevertheless, the relative line intensities of Ca, Mg, K, Na, and Fe could be measured and their relative intensities were consistent with the compositions determined from XRF analyses. Moreover, the relative intensities of the AlO bands were consistent with the known aluminum abundances, in spite of ambiguity contamination by the impactor. The Al emission line near 309 nm, however, appears to be predominately from the impactor since its intensity does not vary with target. Use of a quartz sphere impactor (basalt target) and higher spectral resolution clearly reveals the additional spectra fidelity in the region masked by the AlO bands (Fig. 2). Of particular importance are the diagnostic Fe emissions.

Absolute abundances of the various atomic species require knowledge of their temperatures. A related study is assessing this aspect (5). For our purposes, however, ratios of key elements suffice, with the assumption that they are all part of the same vapor cloud created by nearly identical impacts (mass, velocity, angle). The nearly identical Al emission line intensity on all three experiments are consistent with the further implicit assumption that conditions (e.g., temperature, mass) within this cloud are about the same. Figure 3 reveals that line intensity ratios of K/Ca, Na/Ca, and Fe/Ca against Mg/Ca allow clearly distinguishing between the different meteorite types.

Calibrated Intensities: Our laboratory impacts into solid basalt targets resulted in Ca emission lines with a peak radiant power of about 3.5 W. This delivers about 4 mW/cm^2 of irradiance at the observing distance of our detectors. If earlier studies (1) hold, then radiant power should scale with impactor mass and the fourth power of the velocity. Consequently, a 100 kg impactor striking at 10 km/s should radiate about $3x10^6$ more power than our laboratory results. For a spacecraft observing distance of 100 km, such an impact should generate diagnostic spectral emissions with an irradiance delivered to a spacecraft detector (without additional collector optics) reduced by about 500 relative to our experiments. This irradiance should be readily detected with current technology. We must emphasize, however, that we find significant differences in these results for different impact angles, impact velocities, view areas, target physical state (powder versus block), and time exposure. Consequently, the values cited above are for illustration purposes only and should not be used for specific mission scenarios.

Conclusions: IFS can be used to delineate different meteorite classes. Extrapolation of the observed peak radiant power for impacts at laboratory scales suggests that IFS technology could have a role in future planetary missions. Such an approach would be complementary to standard reflectance spectroscopy by providing elemental (rather than mineral) abundances and by involving materials from below the masking effects from space-weathering. Nevertheless, we also recognize significant effects of impact angle, impact velocity, and physical state of the target that need to be better understood before a viable mission strategy can be developed with confidence.

Impact Flash Spectroscopy: M.A. Adams, P.H. Schultz, S. Sugita, J.D. Goguen

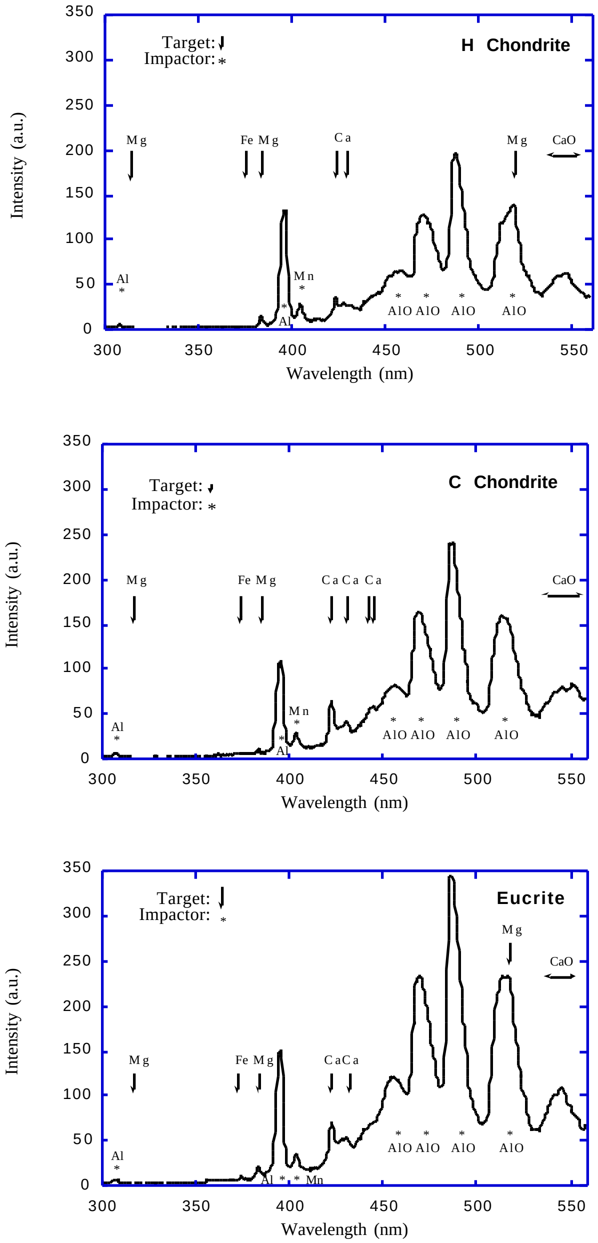

Fig. 1 Diagnostic emission lines produced from impacts into an H-4 chondrite (a), CV-3 chondrite (b), and eucrite (c). Impact velocities (5.5 km/s) and angles (30˚) were nearly the same for all impacts. Differences in AlO, Ca, Mg, and Fe correspond to differences in bulk composition. Quantitative measures are made from expanded scales (not from these plots).

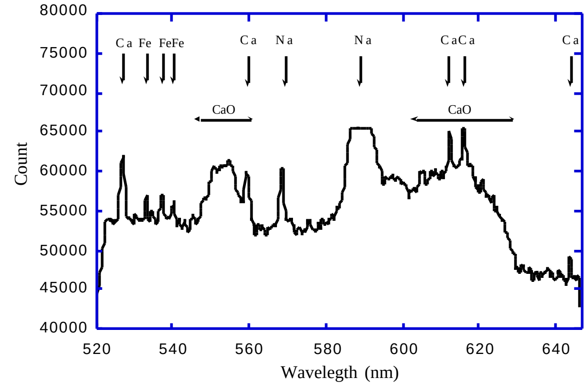

Fig. 2 Higher spectral resolution (1 nm) for a quartz sphere impact into basalt clearly revealing diagnostic Fe emission lines.

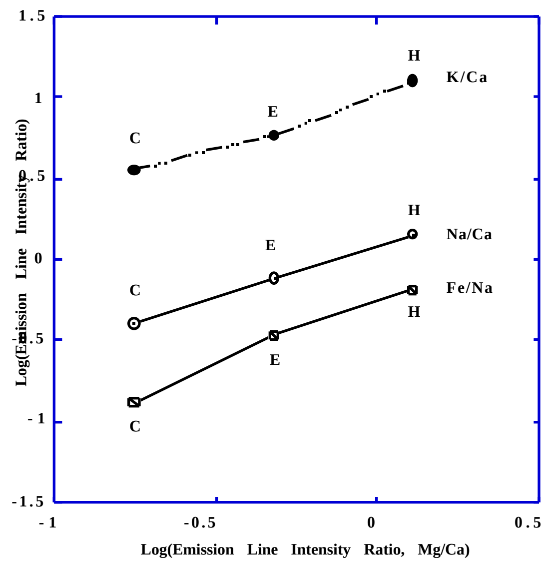

Fig. 3 Spectral intensity ratios of line emissions produced by impacts into a CV-3 chondrite (C), eucrite (E), and H-4 chondrite (H).

References: 1. Gehring, J.W. and Warnica, R.L. (1963) *Proc. 6th Hypervelocity Impact Symposium, Vol. II*, 628. 2. Schultz, P.H. and Crawford, D.A. (1987), *Lunar Planet. Sci. XVIII*, 888-889. 3. Schultz, P.H. (1996), *J. Geophys. Res.*, 21,117-21,136. 4. Schultz, P.H. *et al.* (1996), *Lunar Planet. Sci. XXVII*, 1149-1150. 5. Sugita, S., Schultz, P.H., and Adams, M. (1997), *Lunar Planet. Sci XXVIII* (this volume).